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BASIC SEISMIC ANALYSIS OF REGIONAL EVENTS OBSERVED AT NORSAR

David G. Lambert, et al

Texas Instruments, Incorporated

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BASIC SEISMIC ANALYSIS OF REGIONAL EVENTS OBSERVED AT NORSAR

TECHNICAL REPORT NO. 4

VELA NETWORK EVALUATION AND AUTOMATIC PROCESSING RESEARCH

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This report deals with the basic seismic analysis of small magnitude regional Eurasian events observed at NORSAR. The analysis was severely hampered by the experimental limitations. However, phase energy ratios (P/S) appear promising as a discriminant despite the experimental problems.

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ABSTRACT

This report deals with the basic seismic analysis of small magnitude regional Eurasian events observed at NORSAR. The analysis was severely hampered by the experimental limitations. However, phase energy ratios (P/S) appear promising as a discriminant despite the experimental problems.

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SECTION I
INTRODUCTION

Teleseismic signals from Eurasian events have been studied extensively using data from seismic stations and arrays throughout the world. Various sophisticated signal enhancement techniques have been developed to lower detection and discrimination thresholds. However, many small or low magnitude events occur which are not detected at teleseismic distances, even with the present processing techniques. Small epicentral distances are a necessary requirement for detection of these events, and it is important to have knowledge of the parameters and techniques required for discriminating between regional small shallow-earthquakes and explosions. The nature of discrimination at short distances can be quite different than that for teleseismic distances, because of the differences between regional and teleseismic m_b's and because of the great variety of phases available at regional distances. This report considers some of the problems in regional event discrimination.

In this study we are mainly concerned with the distance range at which the primary wave is refracted horizontally along the Mohorovicic discontinuity (P_n). Pasechnick (1970) indicated that the distance range for the first arrival (P_n) over Eurasia was $\Delta \leq 800$ to 1200 kilometers, which he terms 'first-zone'. The distance range $1200 \leq \Delta \leq 2000$ kilometers he terms the 'second-zone'. Carder (1952) on the other hand, uses the term near regional for $150 \leq \Delta \leq 650$ kilometers and regional $650 \leq \Delta \leq 1600$ kilometers. We use the terms first-zone and regional interchangeably throughout this report but are always refering to distances within the general range of $150 \leq \Delta \leq 2000$ kilometers.

First-zone studies in Eurasia have been reported primarily by Pasechnick (1970). He observed that both earthquakes and explosions from the same regions had the same phases and travel-times but that dynamic characteristics of the phases were different. Laun and Becker (1974) investigated the feasibility of using NORSAR data to examine differences in the dynamic characteristics of these phases. Their overall goals were based on results obtained from extensive studies by many authors of well located events from the Nevada Test Site (NTS) recorded at near regional, regional, and small teleseismic distances. However, for seismic events observed at NORSAR, precise locations, origin times and depths were not possible, especially for those events detected and located by NORSAR alone. Thus, many of the discriminant techniques applied to NTS events were not successful when applied to the NORSAR data. This does not mean that these techniques would not be effective for Eurasian regional events observed at NORSAR if precise hypocenter parameters were known, but only that they were unable to apply them with any degree of confidence to their particular data.

Laun and Becker did find one promising discriminant despite their experimental problems, and that was the P/S energy ratio. Their determination of this ratio utilized broad time windows based on fixed phase velocities (Booker and Mitrinovas, 1964) to reduce the problems due to inaccurate hypocentral locations.

In this report we have enlarged the data base of Laun and Becker. Unfortunately no additional presumed explosions occurred during the time span of this new event ensemble. However, we make some observations and suggestions concerning the experimental problems encountered.

This report is arranged in the following manner: Section II presents the data base. Section III deals with processing and analysis, Section IV presents the results, Section V contains the pertinent conclusions and suggestions, and Section VI gives references.

SECTION II

BASIC DATA

The NORSAR array at Kjeller, Norway was chosen for the source of first-zone data for a number of reasons. The array is situated close to areas where presumed explosions have occurred. The propagation path for these signals is typically continental and the crustal properties in Scandinavia have been studied in detail. As for the array itself, both high quality vertical component short-period data and three component long-period data are recorded there. The NORSAR Data Processing Center also publishes a bulletin of events detected by the array. This bulletin reports many low magnitude regional events which do not appear in the Preliminary Determination of Epicenters (PDE).

These NORSAR data were obtained in two ways. The short-period data are ordered from the Norwegian Data Processing Center at Kjeller, Norway and mailed to the Seismic Data Analysis Center (SDAC) in Alexandria, Virginia. A time lag of approximately three months exists between the data request and having the short-period data on hand for processing. All long-period data are transmitted in real time via a trans-Atlantic communication link to the SDAC and recorded there on magnetic tape. However, data quality problems, combined with the small size of the event data base resulted in having only five events with usable long-period data. Thus, no long-period data results are presented in this report.

A first-zone or regional event list was compiled from both the PDE bulletin and NORSAR bulletin for the period January 1974 through March 1974. Table II-1 lists 60 events and their associated event parameters.

TABLE II-1

EVENT LIST AND PARAMETERS
(PAGE 1 OF 3)

Designation	Date	Origin Time	N Lat.	E Long.	Depth	m_b	Source
NS1-WRUS-01	01-02-74	12:26:33.0	60.3	29.1	-	3.1	N
PS1-TURK-02	01-03-74	07:39:47.0	39.8	26.9	33	4.3	P
NS1-WRUS-03	01-04-74	12:09:47.0	55.9	44.9	-	3.0	N
PS1-CITA-04	01-05-74	07:33:47.0	43.3	12.3	33	3.9	P
PS1-AEGE-05	01-06-74	23:24:17.0	40.2	24.6	33	4.3	P
NS1-WRUS-07	01-11-74	12:20:06.0	59.7	28.0	-	3.4	N
PS1-AEGE-08	01-11-74	21:15:06.0	40.1	24.5	45	3.8	P
NS1-SWRS-09	01-12-74	08:42:04.0	48.0	39.9	-	3.2	N
NS1-ADRI-10	01-14-74	06:38:15.0	43.0	17.0	-	3.0	N
PS1-SGRE-11	01-15-74	17:34:19.0	37.4	21.0	38	4.2	P
NS1-WRUS-12	01-17-74	12:28:28.0	60.2	29.0	-	3.2	N
PS1-TURK-13	01-18-74	10:57:14.0	40.4	28.9	23	4.2	P
NS1-WRUS-14	01-19-74	12:34:40.0	58.4	26.9	-	3.2	N
NS1-WRUS-15	01-22-74	12:18:02.0	59.4	28.4	-	3.1	N
NS1-WRUS-16	01-22-74	12:48:09.0	59.3	28.6	-	3.4	N
NS1-WRUS-18	01-22-74	21:49:23.0	59.4	27.8	-	3.0	N
PS1-GREC-19	01-24-74	09:40:16.0	38.3	20.0	33	4.7	P
NS1-WRUS-20	01-24-74	12:14:45.0	60.1	29.2	-	3.3	N
NS1-WRUS-21	01-24-74	12:39:46.0	59.0	28.0	-	3.0	N
NS1-WRUS-22	01-25-74	12:16:34.0	60.9	29.3	-	3.0	N

TABLE II-1

EVENT LIST AND PARAMETERS
(PAGE 2 OF 3)

Designation	Date	Origin Time	N Lat.	E Long.	Depth	m_b	Source
NS1-WRUS-23	01-25-74	12:27:47.0	58.8	27.6	-	3.0	N
NS1-WRUS-24	01-27-74	09:24:41.0	67.7	34.3	-	3.3	N
NS1-WRUS-25	01-27-74	21:06:44.0	37.5	22.6	-	3.3	N
NS1-FIND-26	01-29-74	12:10:36.0	60.5	28.9	-	3.3	N
PS1-GREC-27	01-29-74	15:12:45.0	38.4	21.8	31	4.3	P
NS1-WRUS-29	01-30-74	14:43:20.0	59.3	24.1	-	3.4	N
NS1-WRUS-30	01-30-74	14:50:34.0	59.4	24.8	-	3.5	N
PS1-TURK-31	02-01-74	00:10:02.0	38.6	27.0	29	5.2	P
NS1-WRUS-32	02-01-74	14:06:17.0	59.7	27.4	-	3.0	N
PS1-TURK-33	02-04-74	23:38:04.0	40.2	27.0	57	3.6	P
NS1-WRUS-34	02-06-74	12:20:29.0	58.6	27.9	-	3.2	N
PS1-TURK-35	02-07-74	08:46:45.0	40.1	26.9	37	4.3	P
NS1-WRUS-36	02-08-74	10:39:29.0	60.3	29.7	-	3.3	N
NS1-WRUS-38	02-13-74	12:12:27.0	59.9	28.7	-	3.1	N
NS1-WRUS-40	02-14-74	13:41:18.0	60.7	29.2	-	3.2	N
NS1-WRUS-42	02-15-74	12:56:03.0	60.0	29.2	-	3.6	N
NS1-WRUS-43	02-15-74	13:26:14.0	58.2	27.5	-	3.2	N
NS1-WRUS-44	02-15-74	14:50:31.0	60.8	29.3	-	3.2	N
PS1-GREC-46	02-17-74	05:03:07.0	38.0	21.7	33	3.9	P
PS1-IONI-47	02-17-74	11:33:15.0	37.3	20.8	8	4.0	P

TABLE II-1

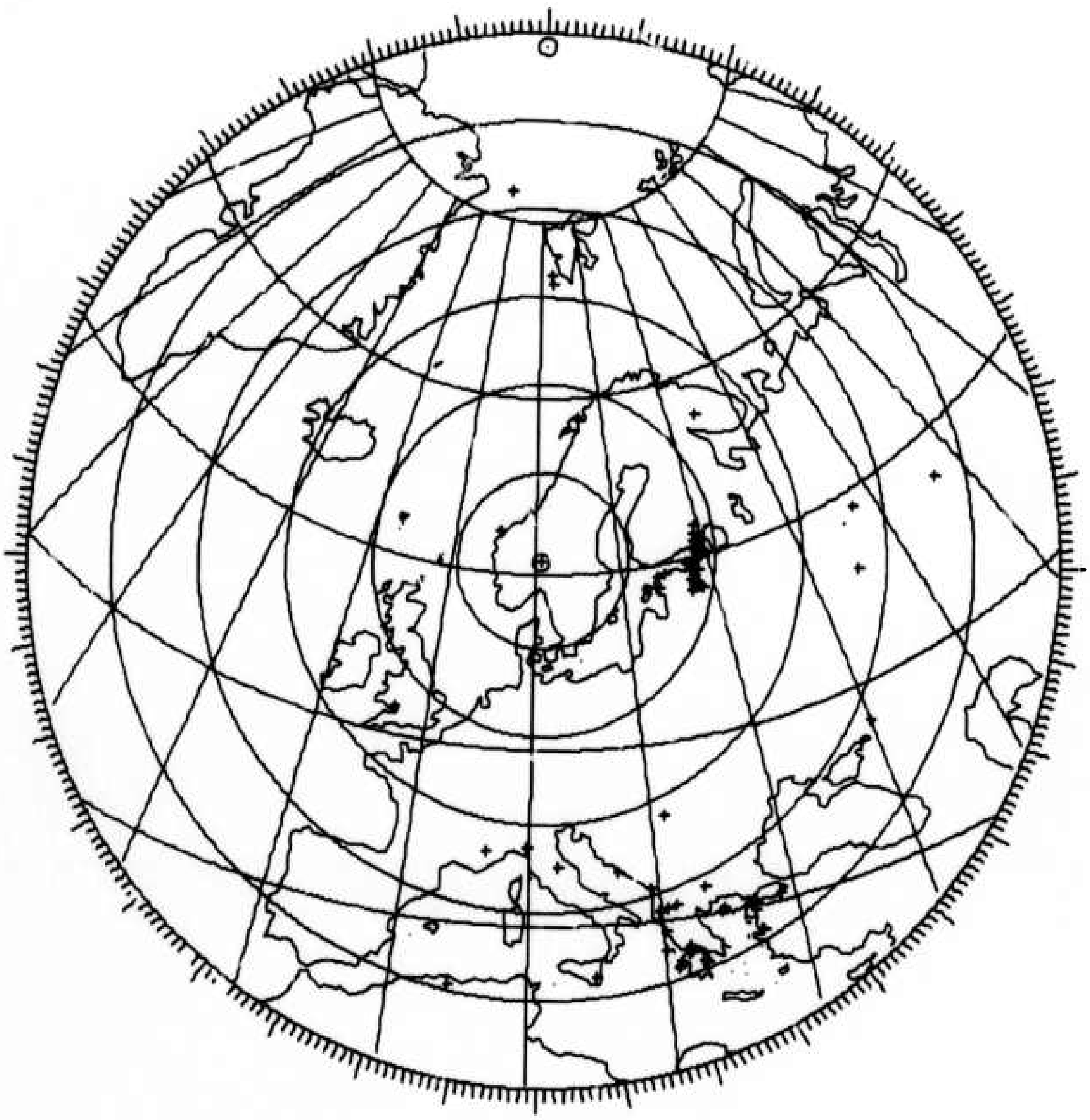
EVENT LIST AND PARAMETERS
(PAGE 3 OF 3)

Designation	Date	Origin Time	N Lat.	E Long.	Depth	m_b	Source
NS1-WRUS-48	02-18-74	13:09:59.0	58.7	24.0	-	3.2	N
NS1-WRUS-50	02-19-74	12:38:53.0	58.3	27.9	-	3.5	N
NS1-FIND-51	02-21-74	12:08:46.0	61.3	29.2	-	3.3	N
NS1-WRUS-52	02-22-74	12:18:27.0	60.8	29.3	-	3.5	N
PS1-GREC-53	02-23-74	01:28:46.0	38.1	21.8	44	4.4	P
PS1-GREC-54	02-23-74	20:55:19.0	38.3	20.2	33	4.4	P
PS1-IONI-57	02-26-74	11:13:21.0	37.2	20.8	33	4.4	P
PS1-NSVA-59	02-28-74	22:18:40.0	81.6	-2.0	33	4.5	P
PS1-SVAL-60	03-03-74	16:22:48.0	76.5	13.1	33	4.2	P
PS1-SVAL-61	03-06-74	00:10:00.0	77.0	12.7	33	3.9	P
PS1-GREC-62	03-10-74	21:51:03.0	40.8	21.2	17	4.1	P
PS1-ALBN-63	03-14-74	20:57:34.0	41.9	19.4	33	4.3	P
PS1-GREC-65	03-22-74	17:02:21.0	40.7	20.5	33	4.7	P
PS1-SICI-66	03-28-74	21:32:35.0	37.1	15.0	33	4.6	P
PS1-ALGE-67	04-07-74	00:56:56.0	36.5	04.4	33	4.2	P
PS1-ALBN-68	04-08-74	00:09:42.0	40.6	19.8	19	3.2	P
PS1-GREC-69	04-09-74	00:31:09.0	39.4	20.2	44	3.1	P
PS1-RUMA-71	04-17-74	01:31:34.0	46.0	21.1	33	5.6	P
PS1-NNOR-73	04-28-74	12:52:50.0	68.7	16.2	33	4.9	P
NS1-URAL-74	04-30-74	14:17:15.0	57.7	56.9	-	3.6	N

P = NOAA-PDE List N = NORSAR List - = No Information

Figure II-1 shows location of NORSAR and the event epicenters, indicated by crosses. The circles about NORSAR are at 5 degree increments. Further, the data reported by Laun and Becker (1974) are also included in this report. The event listing for their data is given in Appendix A.

The accuracy of the event parameter information (Table II-1) varies considerably between source bulletins. The NOAA-PDE information is generally quite reliable since many stations were used to determine epicentral parameters and m_b. On the other hand, for the NORSAR bulletin, the event parameters can have large errors due to beamforming problems associated with regional events (Ringdal and Whitelaw, 1973). Locations errors can be as much as 160 kilometers. Some effects of these problems are discussed in the following sections.



⊕ NORSAR

\+ Event Locations

FIGURE II-1

STATION AND EVENT LOCATION MAP

SECTION III

PROCESSING AND ANALYSIS

A. PROCESSING

The raw NORSAR short-period data were edited from the library tapes from Norway. The edit procedure reformats the single sensor time series, performs simple quality checks, and transfers the data to a working tape. This edit program can handle 192 seconds of data at a rate of 10 samples per second. Two edits of 192 seconds were run for each event. The first starts about 20 seconds before the P arrival while the second edit joins the first to form 384 seconds of contiguous data. Even with 384 seconds of data, some of the later phases for the more distant events were not included in the edit time. The more distant events were included in the ensemble to determine the distance at which the first arrival is the teleseismic P and to compare regional versus teleseismic m_b estimates.

Laun and Becker (1974) determined the sensor which had the best signal-to-noise ratio (SNR) to be the center sensor at subarray four. For this study all event measurements and analysis utilize the data from this seismometer. From inspection of the noise characteristics, they also found that the raw data was generally dominated by two-second period noise so a high-pass filter (from 0.9 to 5.0 Hz) was applied to the data. A second filter was also applied to correct for instrument response. Figure III-1 is a plot of the instrument response for the short-period system at NORSAR.

Phase energy ratio determinations were made using the Seismoprint technique (Cohen, 1969). This technique displays the power of a seismic signal as a function of time and frequency by estimating successive power

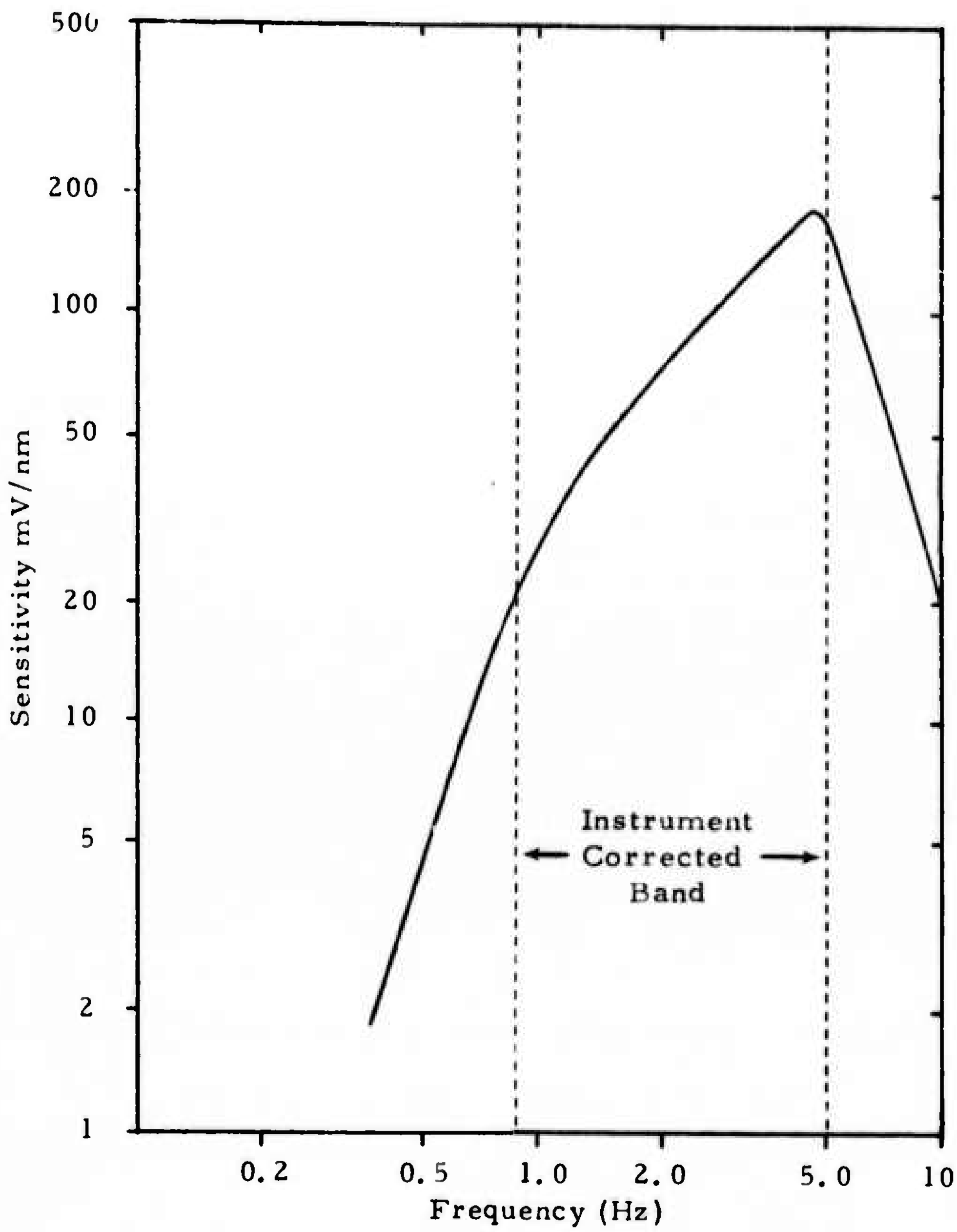


FIGURE III-1

NORSAR SHORT-PERIOD INSTRUMENT RESPONSE

spectra from a set of overlapping time gates of the data. The spectral power in each gate is normalized to the largest power value of the entire set and the resulting spectra are then displayed using two-dimensional printer plots with power coded by letters. All spectral estimates used a 32 point time gate (3.2 seconds), contiguous spectral estimates are separated by 8 points (0.8 seconds). This choice was considered optimum by Cohen, 1969. In addition, the program computed the total power in each time gate for use in the phase energy determinations.

B. VISUAL ANALYSIS

For this analysis, a plot of all subarray sensors was examined to check for continuity of the chosen P phase across the subarray. This prevented picking spurious phases at the reference sensor. In most cases the P wave was clearly visible on these seismograms. For these data arrival times, amplitudes, and periods were measured for estimation of location accuracy and determination of bodywave magnitudes m_b.

SECTION IV
RESULTS

A. TRAVEL-TIMES OF P_n OR P

Table IV-1 lists the observed P travel-times and Figure IV-1 shows the reduced travel-times relative to the Herrin (1968) predicted travel-times for zero and 40 kilometers depth.

The presumed explosion travel-times scatter about the predicted curve with deviation of about 2-3 seconds. On the other hand, the times for earthquakes located by the PDE are greater than those predicted for normal depth. This is especially evident for the four earthquakes located by PDE at distances less than 1800 kilometers which lie near the 0 km depth predicted times. The problem presumably lies with the crust and upper mantle structure (Archambeau, et al., 1969), which probably does not conform to the average world-wide structure inferred from the observations by Herrin. The earthquakes located by NORSAR alone scatter significantly about the Herrin curve, indicating the poor location capabilities of NORSAR (or for that matter, any single array station).

B. BODYWAVE MAGNITUDE (m_b) ESTIMATIONS AT REGIONAL DISTANCES

Bodywave magnitude is an important parameter in many teleseismic discriminants. This section deals with the relationship between m_b's estimated at a single NORSAR instrument at regional distances and those estimated teleseismically by the PDE. The fact that differences exist between

TABLE IV-1

OBSERVED P_n OR P TRAVEL-TIMES AND AMPLITUDES
(PAGE 1 OF 3)

Event	Distance (Degrees)	Azimuth STA-EPI	Phase	Travel-Time Observed (sec)	Period (sec)	A/T (mμ/sec) Peak-to-Peak	m_b
NS1-WRUS-01	8.88	85.9	P_n	125.3	0.30	12.60	4.34
PS1-TURK-02	23.27	147.8	P	304.4	0.95	10 00	3.88
NS1-WRUS-03	18.22	90.7	P	248.6	0.30	10.70	3.98
PS1-CITA-04	17.52	176.9	P	233.4	0.85	3.72	3.61
PS1-AEGE-05	22.33	151.8	P	293.2	0.85	5.75	3.64
NS1-WRUS-07	8.48	90.7	P_n	120.0	0.60	10.30	4.13
PS1-AEGE-08	22.40	152.1	P	295.3	0.90	21.90	4.23
NS1-SWRS-09	20.90	115.0	P	279.5	0.90	7.57	3.68
NS1-ADRI-10	18.26	165.9	P	250.5	0.65	7.41	3.83
PS1-SGRE-11	24.33	160.4	P	315.3	0.70	5.88	3.84
NS1-WRUS-12	8.85	86.6	P_n	124.8	0.90	7.42	4.01
PS1-TURK-13	23.26	143.6	P	307.4	0.70	8.12	3.88
NS1-WRUS-14	8.39	100.3	P_n	119.4	0.75	9.53	4.10
NS1-WRUS-15	8.76	92.2	P_n	124.7	0.85	8.91	4.08
NS1-WRUS-16	8.89	92.6	P_n	119.8	0.70	10.70	4.17
NS1-WRUS-18	8.47	92.8	P_n	120.4	0.60	7.75	4.01
PS1-GREC-19	23.29	161.9	P	306.0	0.95	91.10	4.93
NS1-WRUS-20	8.97	87.1	P_n	127.4	0.60	12.00	4.23
NS1-WRUS-21	8.70	95.1	P_n	122.2	0.40	5.47	3.86
NS1-WRUS-22	8.87	82.0	P_n	125.3	0.60	2.04	3.45

TABLE IV-1

OBSERVED P_n OR P TRAVEL-TIMES AND AMPLITUDES
(PAGE 2 OF 3)

Event	Distance (Degrees)	Azimuth STA-EPI	Phase	Travel-Time Observed (sec)	Period (sec)	A/T ($m\mu$/sec) Peak-to-Peak	m_b
NS1-WRUS-23	8.57	96.9	P_n	121.9	0.50	5.76	3.89
NS1-WRUS-24	12.06	45.9	P	168.6	0.60	10.60	4.28
NS1-WRUS-25	24.50	157.4	P	326.2	0.70	7.07	3.95
NS1-FIND-26	8.74	84.8	P_n	124.5	0.50	7.59	4.02
PS1-GREC-27	23.50	158.4	P	306.9	0.60	17.39	4.23
NS1-WRUS-29	6.70	98.0	P_n	94.7	0.30	13.49	4.11
NS1-WRUS-30	7.00	96.3	P_n	99.1	0.75	6.76	3.85
PS1-TUKY-31	24.40	148.6	P	318.8	0.85	53.60	4.81
NS1-WRUS-32	8.20	91.2	P_n	115.6	0.50	6.45	3.92
PS1-TURK-33	22.90	147.3	P	299.4	0.80	4.36	3.57
NS1-WRUS-34	8.80	97.7	P_n	124.8	0.35	10.70	4.17
PS1-TURK-35	23.00	147.6	P	302.3	0.85	5.75	3.70
NS1-WRUS-36	9.20	85.5	P_n	130.5	0.50	11.50	4.22
NS1-WRUS-38	8.80	88.6	P_n	123.8	0.40	10.70	4.17
NS1-WRUS-40	8.90	83.3	P_n	131.3	0.30	8.39	4.06
NS1-WRUS-42	9.00	87.8	P_n	135.0	0.30	13.30	4.27
NS1-WRUS-43	8.80	100.7	P_n	127.8	0.30	7.23	3.99
NS1-WRUS-44	8.90	82.6	P_n	129.1	0.40	6.06	3.92
PS1-GREC-46	23.90	158.8	P	311.9	0.70	14.69	4.20
PS1-IONI-47	24.40	160.9	P	318.8	0.85	5.75	3.84

TABLE IV-1

OBSERVED P_n OR P TRAVEL-TIMES AND AMPLITUDES
(PAGE 3 OF 3)

Event	Distance (Degrees)	Azimuth STA-EPI	Phase	Travel-Time Observed (sec)	Period (sec)	A/T ($m\mu$/sec) Peak-to-Peak	m_b
NS1-WRUS-48	6.90	102.9	P_n	-	0.30	3.74	3.57
NS1-WRUS-50	8.90	99.5	P_n	129.7	0.40	12.90	4.25
NS1-FIND-51	8.80	79.4	P_n	127.9	0.50	4.67	3.81
NS1-WRUS-52	8.90	82.6	P_n	129.6	0.50	12.31	4.23
PS1-GREC-53	23.80	158.6	P	309.3	0.95	18.60	4.29
PS1-GREC-54	23.30	161.5	P	306.1	0.85	10.70	4.00
PS1-IONI-57	24.50	160.9	P	317.3	0.85	7.08	3.94
PS1-NSVA-59	21.00	354.7	P	282.7	0.85	38.00	4.38
PS1-SVAL-60	15.60	1.8	P	218.4	0.40	13.49	4.36
PS1-SVAL-61	19.70	1.4	P	226.2	0.90	6.76	3.61
PS1-GREC-62	21.10	158.1	P	283.7	0.85	9.76	3.79
PS1-ALBA-63	19.70	161.2	P	-	0.85	3.89	3.86
PS1-GREC-65	21.00	159.6	P	283.5	0.80	5.62	3.55
PS1-SICI-66	23.90	172.1	P	313.2	0.70	3.99	3.62
PS1-ALGE-67	24.80	192.7	P	320.5	0.90	7.41	3.99
PS1-ALBN-68	21.00	161.1	P	284.0	0.50	10.50	3.82
PS1-GREC-69	22.20	161.0	P	294.5	0.90	5.24	3.59
PS1-RUMA-71	16.00	153.8	P	225.8	0.80	3.46	3.74
PS1-NNOR-73	8.10	13.5	P_n	118.4	-	-	-
NS1-URAL-74	23.20	77.4	P	310.5	0.60	5.37	3.78

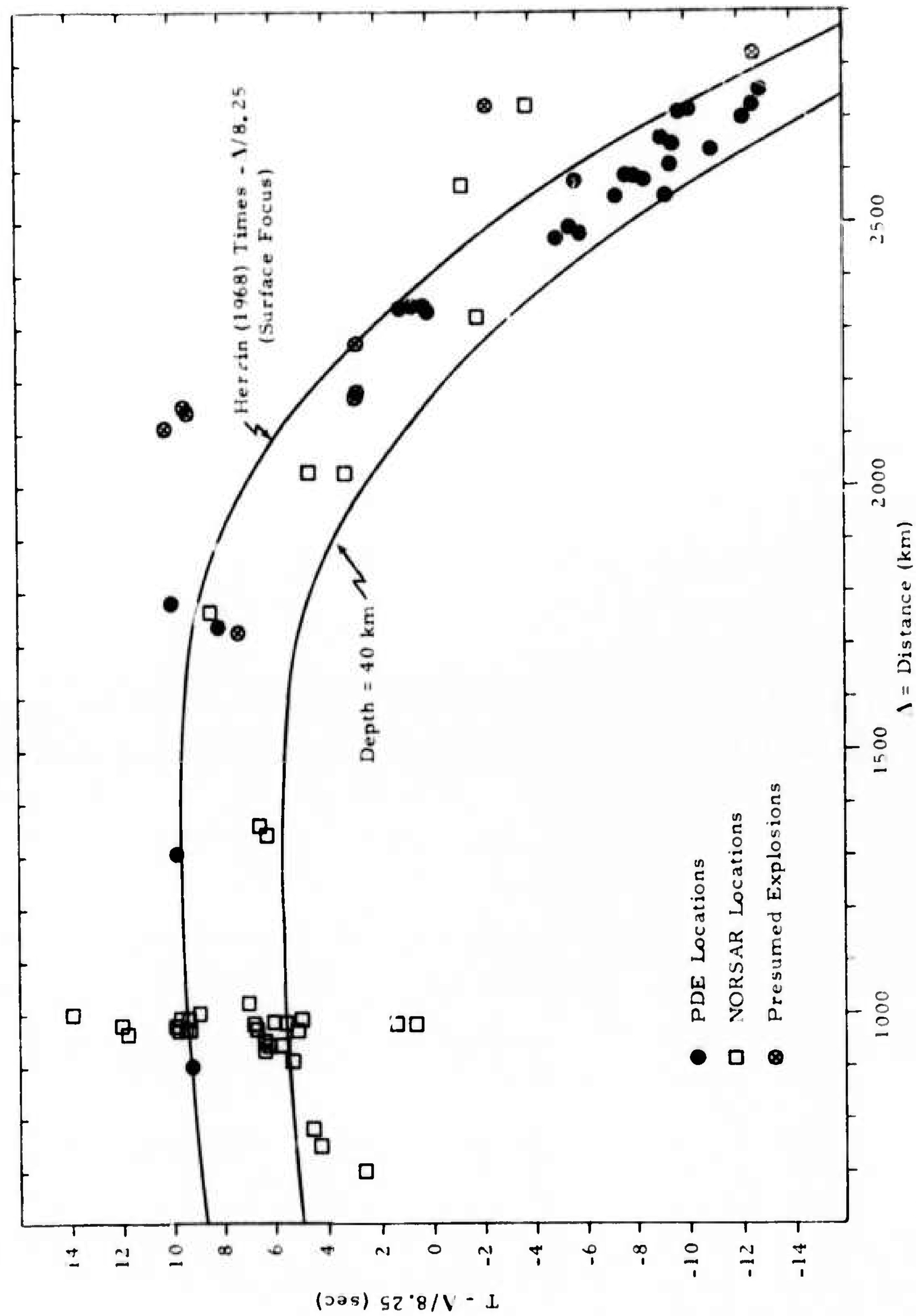


FIGURE IV-1

REDUCED P TRAVEL-TIMES

regional m_b estimates and those for teleseismic distances is well known (Bungum and Husebye, 1974). For this study NOAA-PDE m_b values computed utilizing stations at distances less than 20 degrees were routinely recomputed omitting the close-in stations in order to ensure that they were the 'true' teleseismic m_b's.

Figure IV-2 shows the NORSAR single instrument m_b estimates minus the reported NOAA-PDE or NORSAR beamed m_b's. We show these data as a function of distance to ascertain whether the standard distance factors (B^o) used were suitable for the calculation of m_b in Eurasia. However, the scatter of the data is too large to make any conclusion concerning this problem.

It is apparent that there are two populations formed by this single subtraction. The NORSAR single instrument m_b's are larger than those determined from the NORSAR beams by about 0.8 magnitude units, while those determined from NOAA-PDE are larger than the single instrument NORSAR m_b's by about 0.3 to 0.4 magnitude units.

Bungum and Husebye (1974) indicate a bias of about 0.2 magnitude units between the teleseismic NORSAR beam and NOAA-PDE m_b's. This is compatible with the bias found here. Further, they found that the bias for the NORSAR beamed m_b's for various distances and regions are dependent on event magnitude. These results are mostly due to the threshold bias problem which arises when PDE magnitudes are calculated by averaging over detecting stations only (Ringdal, 1975). A plot of NOAA-PDE magnitudes versus NORSAR single site magnitudes confirms this threshold bias while suggesting that some bias may be due to propagation effects. The data sample is too small to verify the latter conjecture.

The NORSAR beamed estimates are comprised of many small magnitude events ($m_b \leq 3.6$) and the large NORSAR beam-single sensor difference (0.8 magnitude units) is due primarily to beamforming losses intensified by the presence of relatively high frequency energy. This high frequency

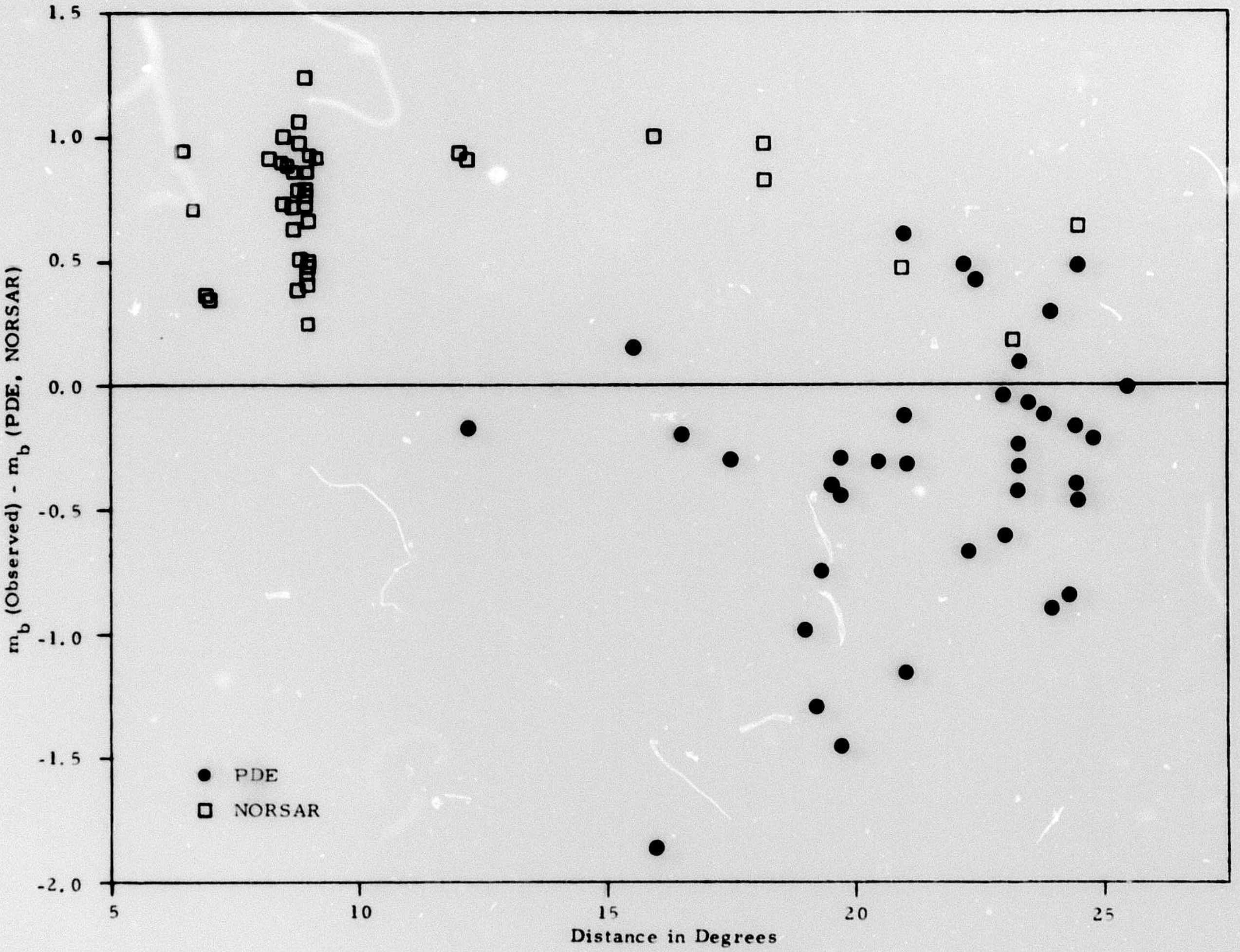


FIGURE IV-2

NORSAR SINGLE INSTRUMENT m_b - m_b REPORTED BY PDE OR NORSAR
AS A FUNCTION OF DISTANCE

energy increases beamforming losses because of greater signal dissimilarity at high frequencies across the array.

In Figure IV-3 the high frequency content is clearly visible in trace 1, a single sensor high-pass filtered NORSAR trace, just after the signal arrival time. In fact this signal would not have been detected, were it not for the presence of this energy. Trace 2 shows the same time series corrected for the NORSAR instrument response and no signal is present. Hence an instrument peaking around 1.0 Hz would probably not have detected this event. The NORSAR instrument peaks at 5.0 Hz, and is ideal for the detection of small regional events.

Summarizing, we find a negative bias of 0.2 to 0.4 magnitude units for m_b and slow travel-times for regional events observed at NORSAR. This suggests low velocity and possibly high attenuation in the crust and upper mantle along the propagation paths to NORSAR, although this result is only suggested by the data.

The scatter of single-instrument NORSAR m_b estimates prevents the determination of a conventional constant station correction. Secondly, the relationship between the NORSAR beamed m_b estimates for the small events ($m_b \leq 3.6$) and the teleseismic magnitudes is unknown. This relationship can not be extrapolated from these data and can not be determined experimentally, due to the lack of corresponding PDE magnitudes.

C. P/S ENERGY RATIOS

As discussed earlier, many of the locations were not well defined and hence individual phases were often not identified due to timing errors. That being the case comparison of amplitudes and times between phases might be misleading and we concentrate on gross differences between the two sources as did Booker and Mitrinovas (1964).

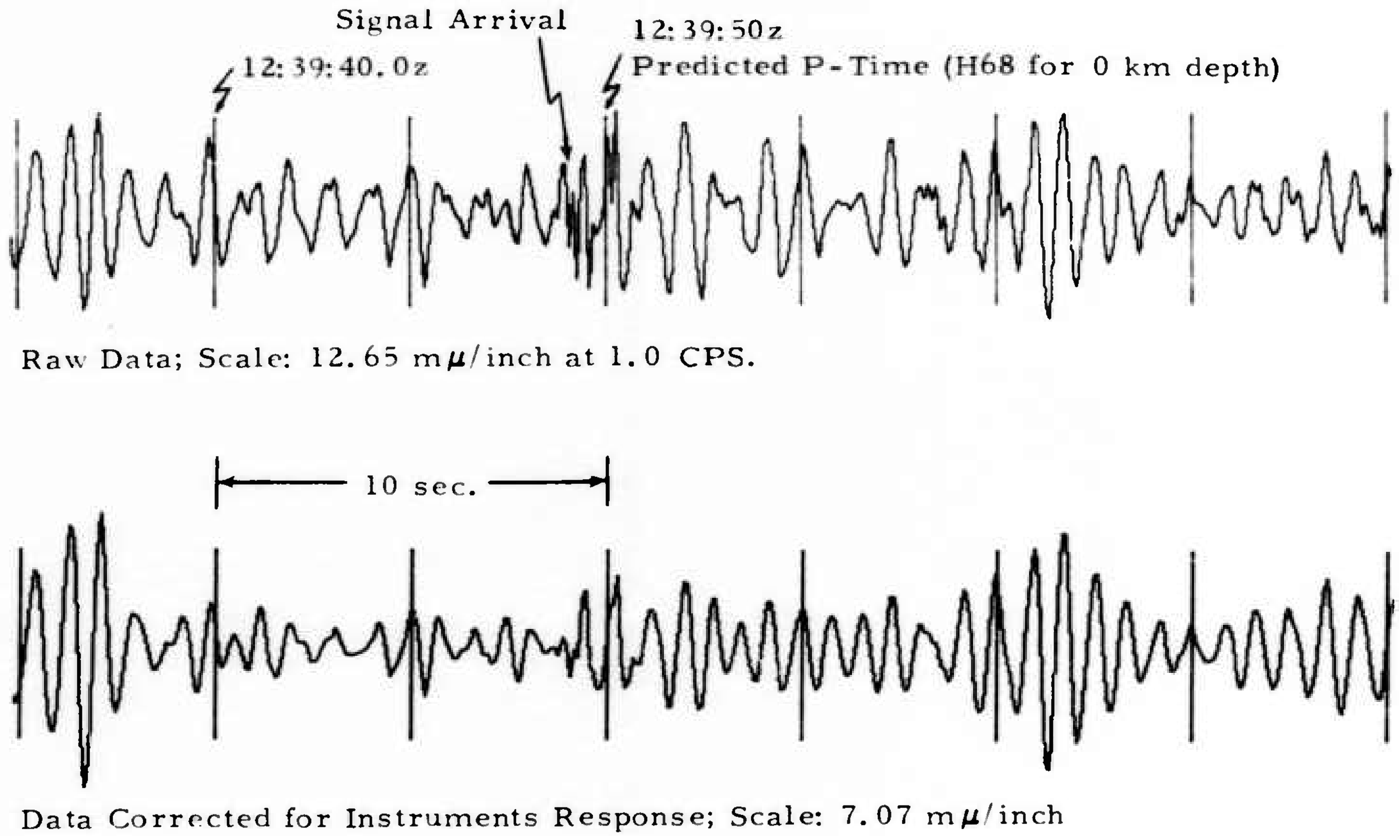


FIGURE IV-3

NORSAR SEISMOGRAMS FOR A WESTERN RUSSIA EARTHQUAKE
(NS1-WRUS-23) AT $\Delta = 8.57^{\circ}$

The short-period seismogram was divided into three broad time frames to take advantage of the differences between earthquakes and explosions. These three time frames contain predominantly compressional wave energy, shear wave energy, and surface wave energy, in that order, and are based on approximate measured travel-time using the following velocity windows:

- P 8.6 km/sec to 5.0 km/sec
- S 5.0 km/sec to 4.0 km/sec
- Rg 4.0 km/sec to 3.0 km/sec.

The total power in each spectrum computed by the seismoprint program was summed over the times corresponding to these velocity ranges, and the ratios between them computed. Because the short-period record length was limited to 384 seconds, the complete Rg phase for $\Delta > 15^o$ was not available and the complete S phase for $\Delta > 20^o$ was also not available.

Figure IV-4 shows the P/S energy ratios as a function of distance. Several general observations can be made:

- There is separation using this criterion between presumed explosions and earthquakes but there are too few presumed explosions to state any conclusions with confidence. Laun and Becker (1974) showed the same presumed explosion data and it is unfortunate that no additional presumed explosions were available for analysis during the time span of our event ensemble.
- P/S ratios for earthquakes having epicenters determined by PDE are more consistent (i.e., have less scatter) than for those located by NORSAR. However, there are only 5 such values which are certainly not enough for a good statistical sample.

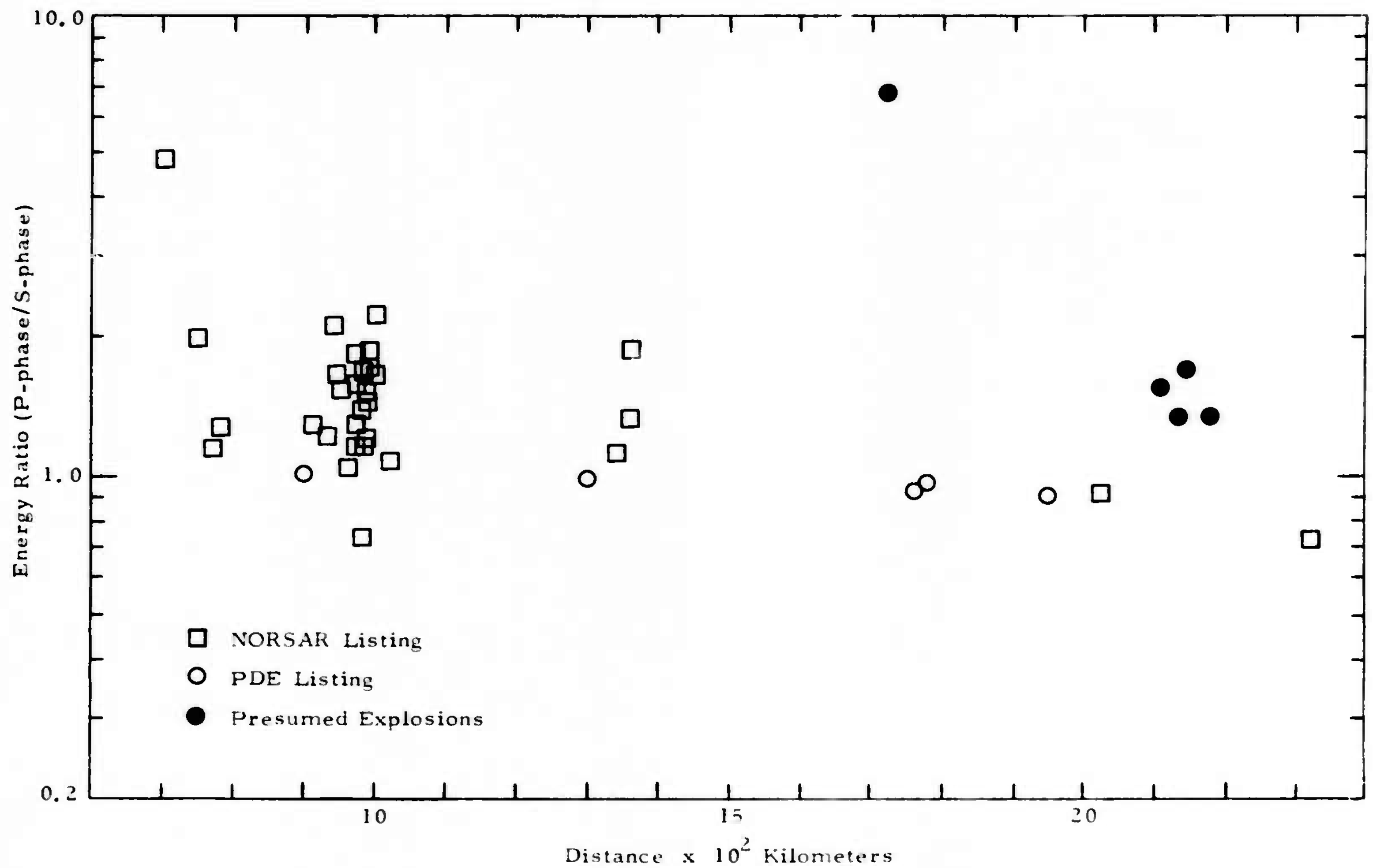


FIGURE IV-4

P/S ENERGY RATIOS

- Laun and Becker discussed a presumed explosion and earthquake which occurred within one degree of each other in western Russia and about 1700-1800 kilometers distance from NORSAR. Our ensemble of data added one earthquake (PSI-RUMA-71) located in Rumania, whose P/S ratio was similar to that of the western Russia earthquake.

- The presumed explosions occurring at distances of about 2150 kilometers are from Novaya Zemlya. All of them have about the same P/S ratios. However, there are insufficient earthquake data to make any statements concerning the degree of separation between source types at this distance.

It is clear that we need more presumed explosion data (P/S ratios) to determine with conficence what the degree of separation, if any, is possible with this criterion.

SECTION V
SUMMARY

In the basic analysis of small regional events observed at NORSAR, we have looked at P travel-times, bodywave magnitudes and one promising discriminant, short-period vertical P/S energy ratios.

Errors in epicenter locations resulted in erroneous station to epicenter distances and consequently analysis of phases other than P were questionable. m_b estimates are biased by the presence of relatively high frequency energy, erroneous distances, and upper mantle structural effects.

P/S energy ratios appear promising as a discriminant even with this poor experimental setup. Ideally one should have a network of stations observing seismic events at regional to small teleseismic distances. With such an experimental plan, event locations (hypocenters) could be made with sufficient accuracy to conduct a complete first-zone study. Unfortunately, such data for Eurasia was not currently available.

SECTION VI
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APPENDIX A

EVENT LIST AND EVENT MEASUREMENTS FROM LAUN AND BECKER (1974)

EVENT LIST AND PARAMETERS

LAUN AND BECKER (1974)

	Designation	Date	Origin Time	Lat.	Long.	Depth	m_b	List
1.	WES/262/11N	09-19-71	11:00:06.8	57.8N	41.1E	0.0	4.5	P*
2.	KOL/248/07N	09-04-72	07:00:03.6	56.7N	33.4E	7.0	4.6	P
3.	FIN*156*06S	06-05-73	06:29:35.0	61.0N	24.0E	0.0	3.1	N
4.	WRS*166*12N	06-15-73	12:52:01.0	58.0N	42.0E	33.0	3.2	N
5.	WRS*180*155	06-29-73	15:54:54.0	61.0N	29.0E	0.0	3.5	N
6.	FIN/188/10S	07-07-73	10:51:25.0	60.0N	29.0E	0.0	3.4	N
7.	WRS*222*12N	08-10-73	12:54:00.0	61.0N	29.0E	33.0	3.3	N
8.	WRS*227*14S	08-15-73	14:08:35.0	60.0N	29.0E	0.0	3.5	N
9.	NVZ/255/06N	09-12-73	06:59:54.3	73.3N	55.2E	0.0	6.8	P*
10.	NVZ/270/06N	09-27-73	06:59:58.0	70.8N	53.9E	0.0	6.0	P*
11.	WRS*270*13S	09-27-73	13:10:53.0	60.0N	29.0E	0.0	3.5	N
12.	WRS/273/04N	09-30-73	04:59:57.5	51.6N	54.6E	0.0	5.2	P*
13.	NOR*276*12N	10-03-73	12:06:40.0	70.0N	31.0E	33.0	3.3	N
14.	FIN*281*12N	10-08-73	12:45:10.0	60.0N	29.0E	33.0	3.3	N
15.	NOR*293*14N	10-20-73	14:21:37.0	70.0N	31.0E	33.0	3.2	N
16.	URA/299/05N	10-26-73	05:59:57.6	53.7N	55.4E	0.0	4.8	P*
17.	NVZ/300/06N	10-27-73	06:59:57.4	70.8N	54.2E	0.0	6.9	P*
18.	NVZ/300/08N	10-27-73	08:03:56.3	70.8N	53.2E	0.0	4.2	P*
19.	NVZ/300/0831	10-27-73	08:21:20.7	70.9N	52.9E	0.0	4.4	P*
20.	NVZ/300/09N	10-27-73	09:13:51.3	71.3N	51.9E	0.0	4.8	P*

Abbreviations:

* = Presumed explosions
P = NOAA-PDE Bulletin
N = NORSAR Bulletin

MAGNITUDE MEASUREMENTS FROM THREE SOURCES

LAUN AND BECKER (1974)

Event Number	NOAA-PDE m_b **	NORSAR Beam m_b	NORSAR Single-Site m_b
1 *	4.5	ND	4.31
2	4.6	ND	4.43
3	-	3.1	4.05
4	-	3.2	4.21
5	-	3.5	3.88
6	-	3.4	3.90
7	-	3.3	3.93
8	-	3.5	3.75
9 *	6.8	ND	6.50
10 *	6.0	ND	5.59
11	-	3.5	3.90
12 *	5.2	ND	5.19
13	-	3.3	ND
14	-	3.3	3.78
15	-	3.2	4.11
16 *	4.8	4.9	5.29
17 *	6.9	ND	5.45
18 *	4.2	3.4	3.46
19 *	4.4	3.1	3.40
20 *	4.8	3.8	3.82

** Recomputed using teleseismic m_b values only

* Presumed explosion

ND Not Detected

- No value given